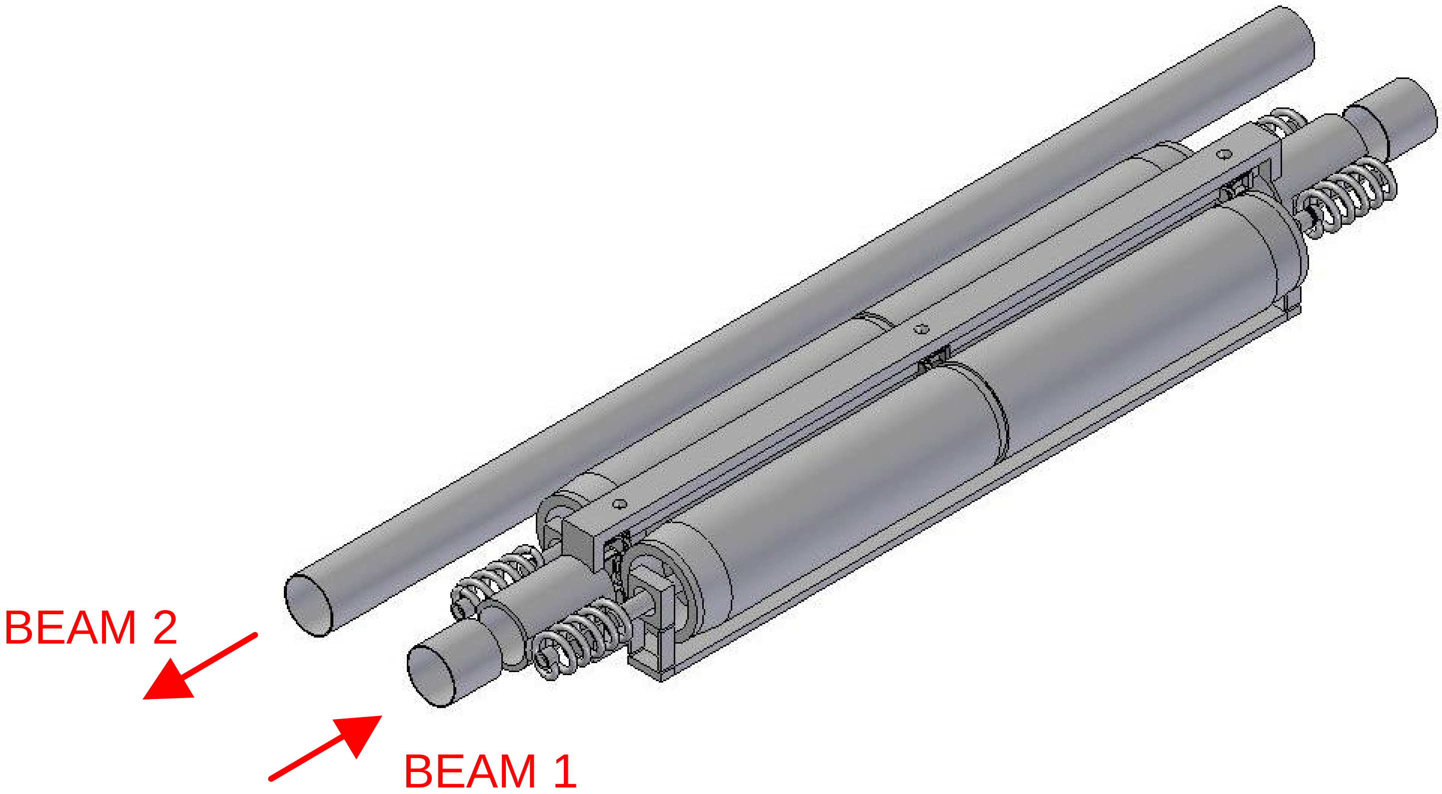
# LARP Collimation
# – Engineering & Analysis

## Adapting the NLC Consumable Collimator to LHC Phase II Secondary Collimation



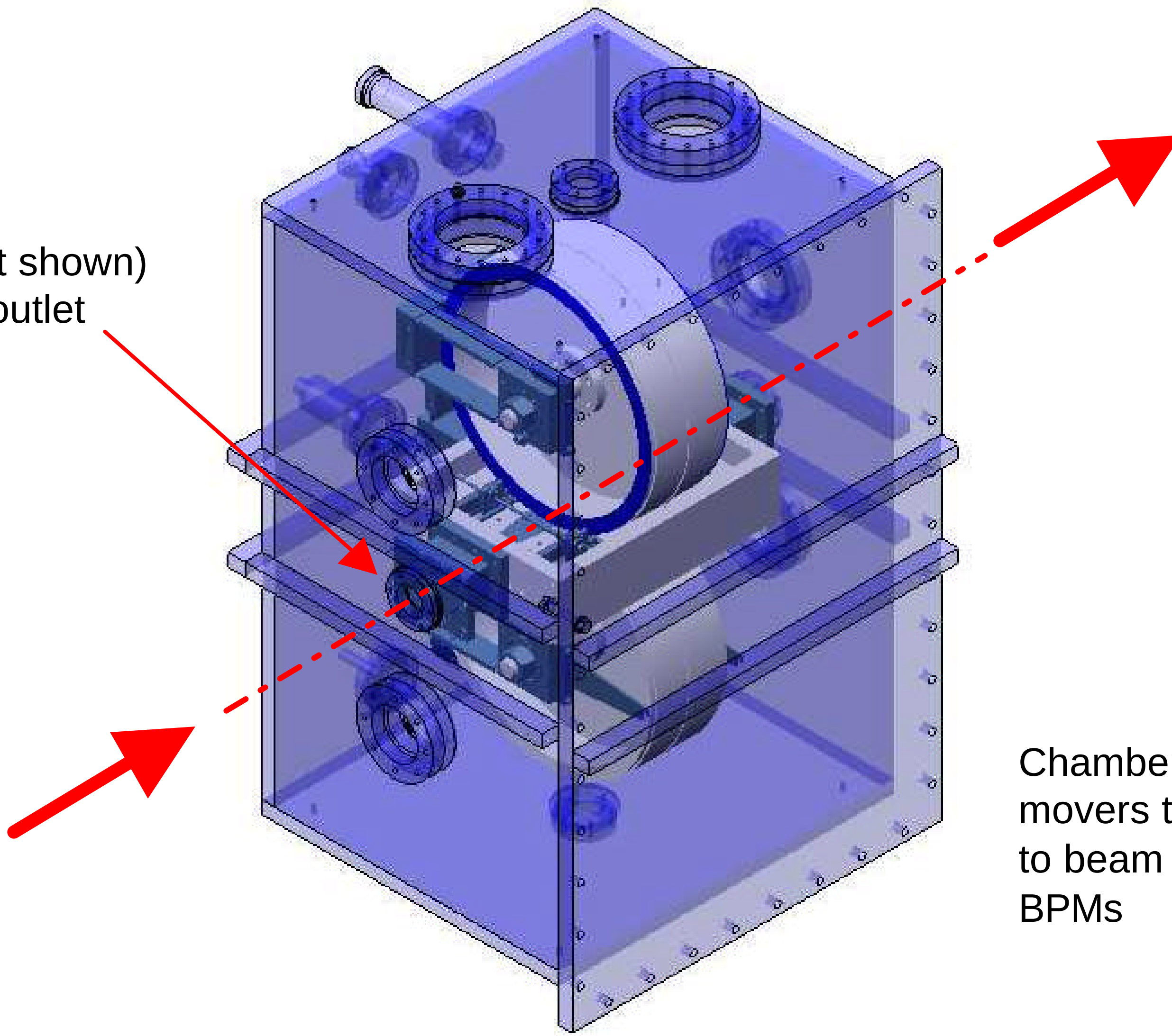
# LARP Collimation – Engineering & Analysis

Overview

1. Review functioning of NLC consumable collimator
2. Compare NLC & LHC requirements
3. Preliminary design: consumable collimator as adapted to LHC
4. Thermal performance of candidate materials
5. Unresolved issues

# NLC Consumable Collimator

BPMs (not shown) at inlet & outlet

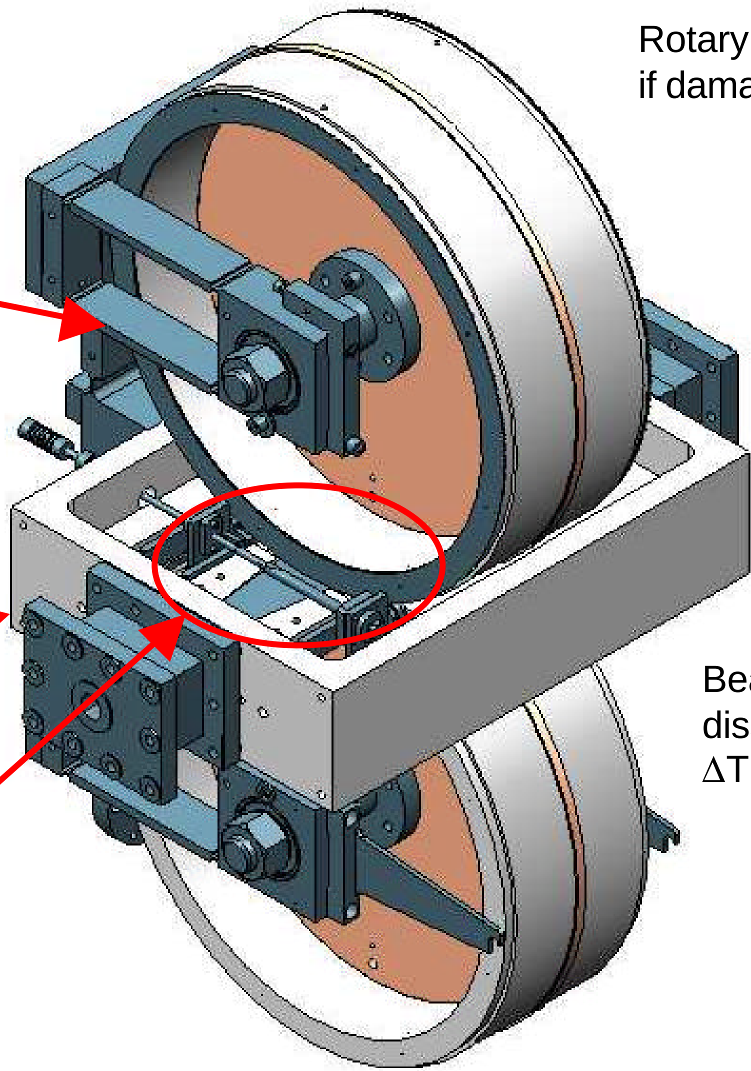


Chamber mounted on movers to align collimator to beam as sensed by BPMs

# NLC Consumable Collimator

Parallelogram links, flexure pivots, Control translation of jaws, minimize friction.

Rotary jaws can be indexed if damaged by beam

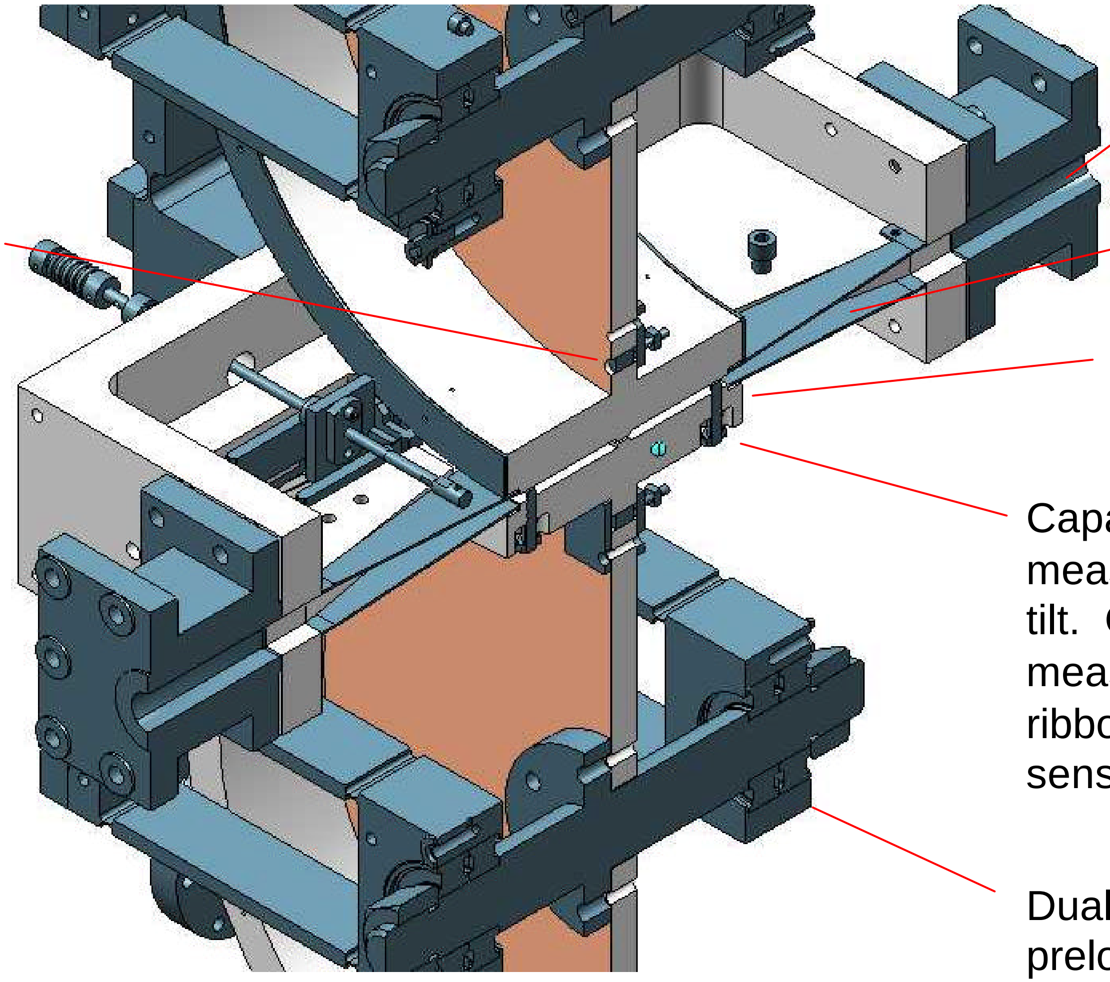


Rigid datum structure, closely coupled to incoming/outgoing BPMs (not shown)…isolates mechanism from mechanical deformations (e.g. atmospheric pressure variations).

Beam induced heat dissipated by radiation. $\Delta T = 42C$ @ 10W/jaw

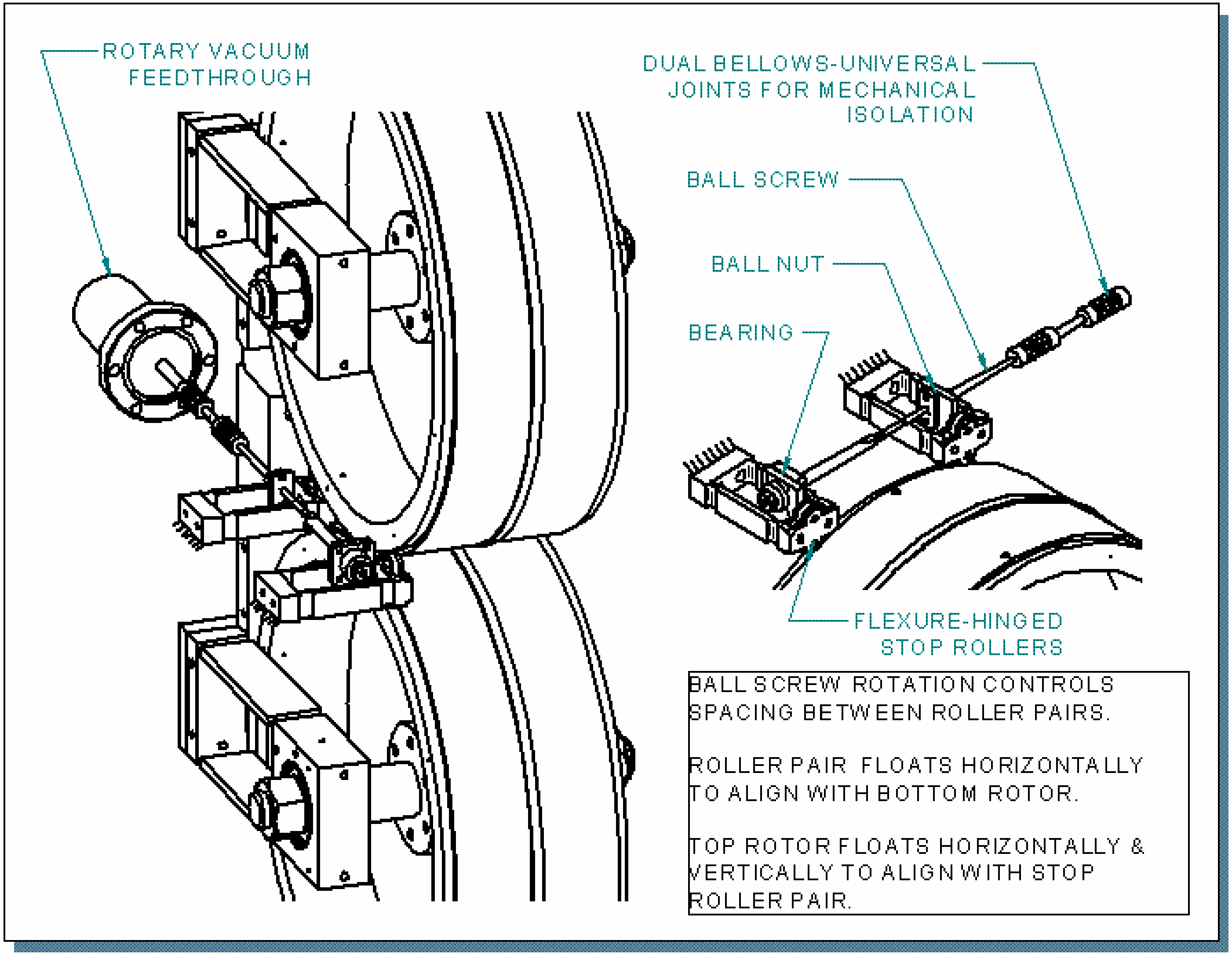
Aperture control mechanism: Thermal effects limited to this region

# NLC Test Unit (Background – not essential)



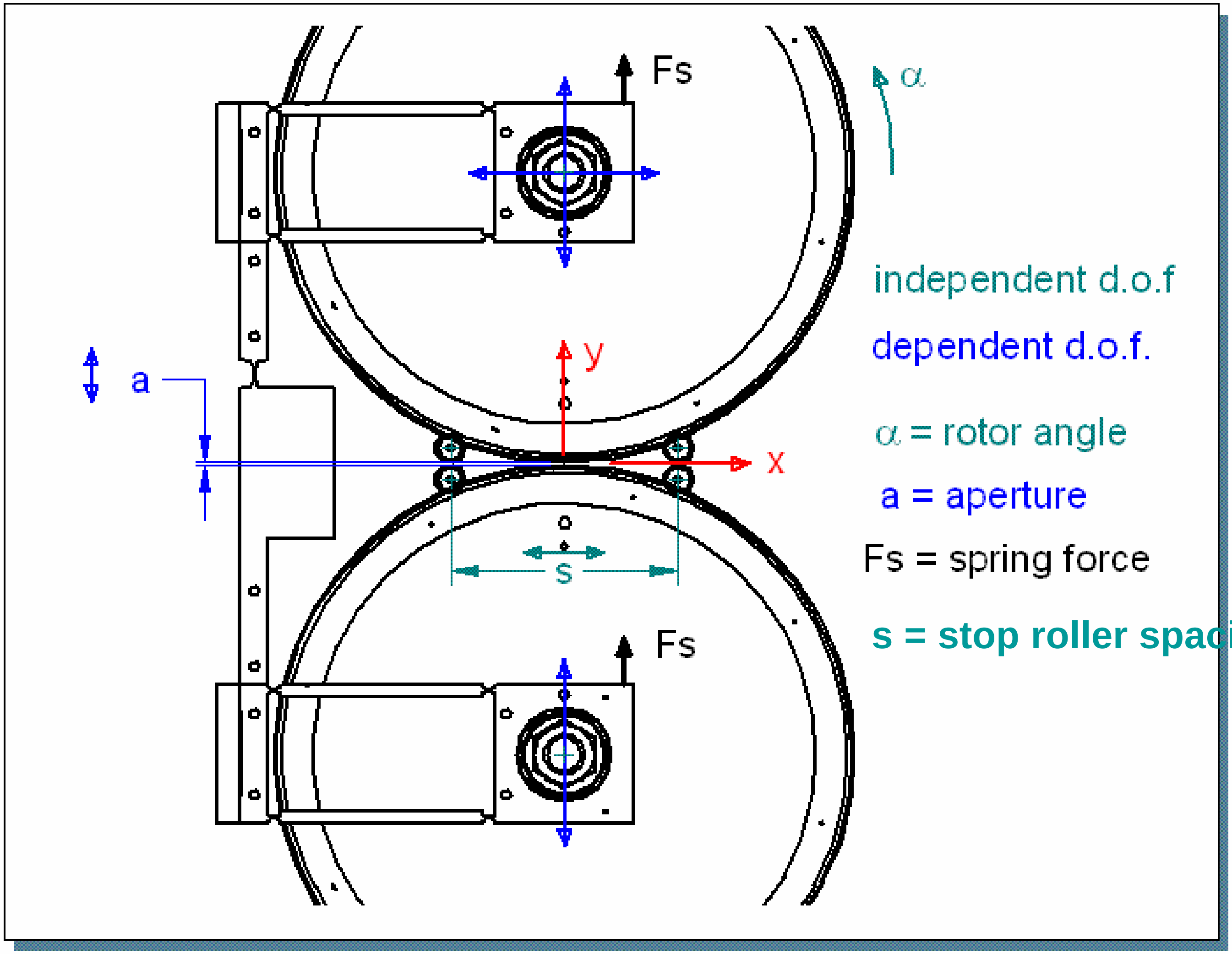
# NLC Aperture-control Mechanism

Flex-pivot parallelogram linkages guide stop rollers. Stop rollers position the jaws.



# NLC Aperture-Defining Geometry

One independent variable (stop roller spacing) defines aperture.



# Major Differences - NLC & LHC Specs

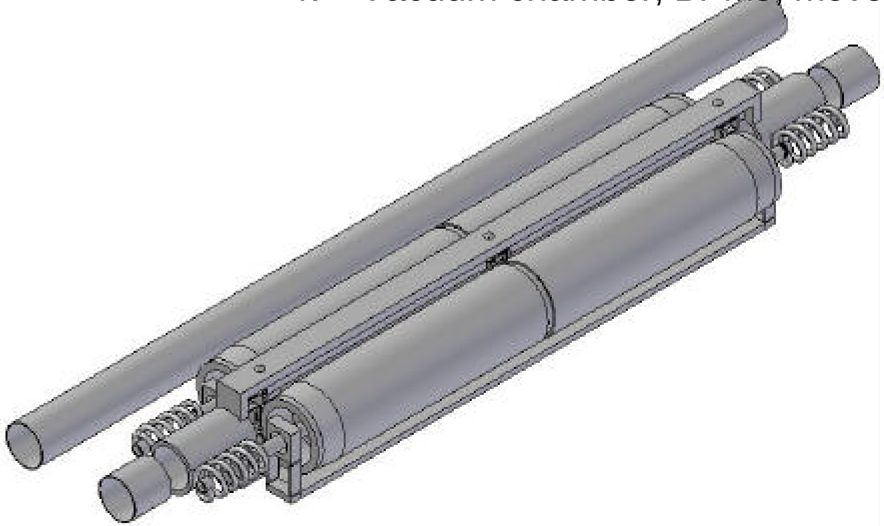
| Specification | NLC | LHC | Comments |
|---|---|---|---|
| beam pipe ID | 1cm | 8.4cm (224mm between opposing beam axes) | LHC spatial constraints |
| jaw length | ~6mm Cu + 2x 5cm Be taper | 1m + 2x 100cm taper | LHC jaw tilt-stability |
| full gap | 0.2 – 2.0mm | 0.5 – 60mm | LHC spatial constraints |
| steady state power (1 hr beam lifetime) | ~1W – 10W per jaw | ~1kW – 10kW per jaw (material dependent) | LHC requires water cooling |

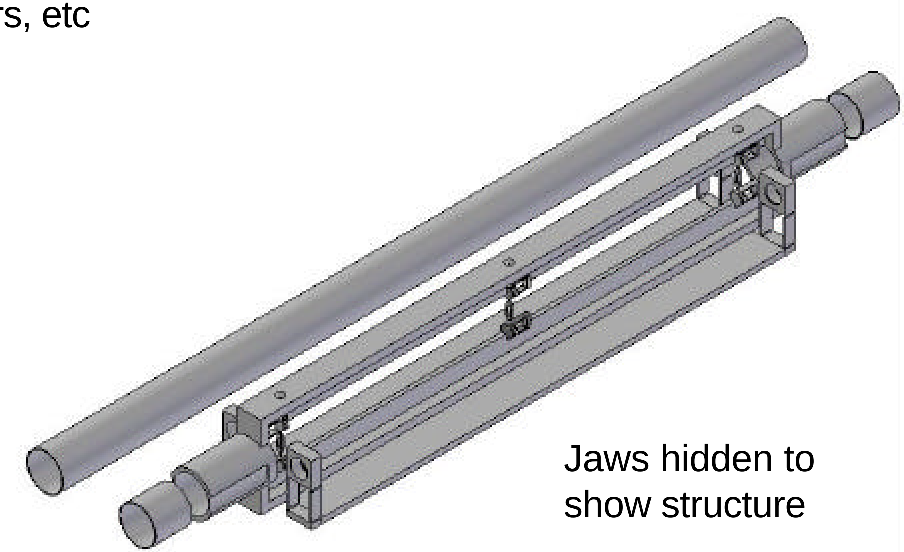
# LHC Collimator Mechanism Concept

## End and center aperture stops included in same model

Note: Conceptual model. Not much detail engineering yet. Not included:

1. Rotary jaw indexing mechanism
2. Loading springs which hold jaws against aperture stops
3. Open aperture power-off mechanism
4. Vacuum chamber, BPMs, movers, etc



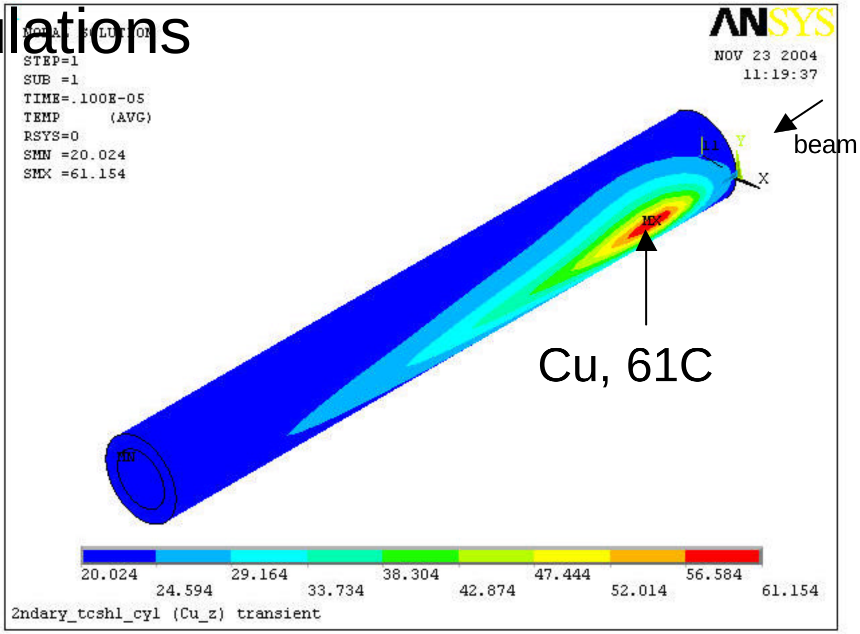


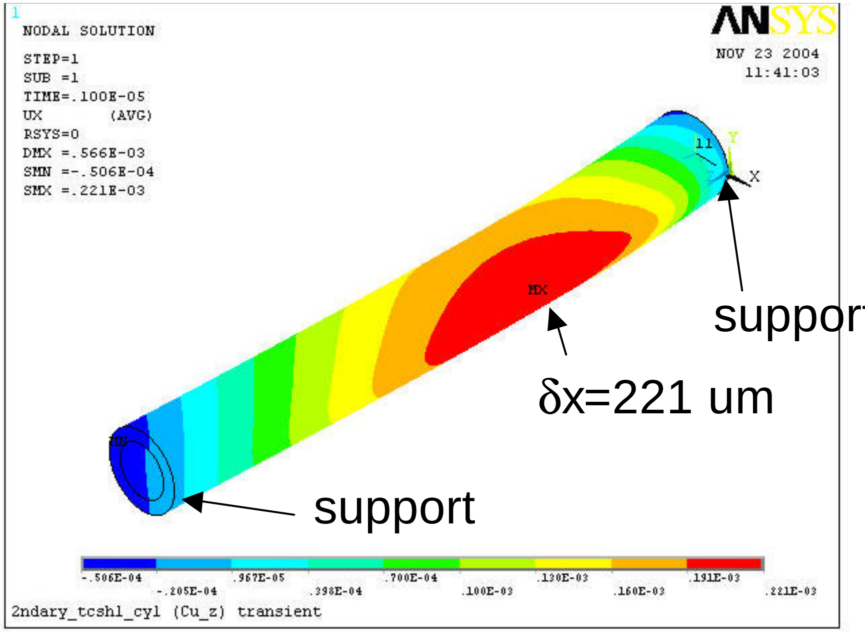
Jaws hidden to show structure

- 1.2m long jaws
- Helical coolant supply tubes flex, allow one rev of jaw
- Jaws supported a both ends for stability, allow tilt control
- Alternative: jaws supported in center
    - thermal deflection away from beam
    - no tilt control

# Thermal Distortion Simulations

- 150mm OD, 25mm wall, 1.2m long
- Simply supported
- ANSYS simulation: FLUKA energy deposit for 10x10x24 rectangular grid mapped to similar area of cylinder
- Most cases: TCSH1 receives 80% of debris from primary (TCPV) plus 2.5% of direct beam per jaw. TCSH1 at 10σ.
- Steady state: 1hr beam lifetime
- Transient:10 sec @ 12 min beam lifetime
- I.D. water-cooled 20C, h=11880 W/m^2/C
    - -Temperature rise of $H_2O$ not modeled
- Materials: Al, 2219 Al, Be+Cu, Cu, Invar, Inconel
    - -Ti, W rejected based on 2-D analysis
- Variations
    - - 45$^{o}$ of ID nearest to beam cooled (not whole 360$^{o}$)
    - - solid cylinder (not thick wall) 45$^{o}$ cooled



# Material Comparison for SS & Transient Thermal Deflection

| primary debris + 5% direct hits | | SS @ 1 hour beam life | | | transient 10 sec @ 12 min beam | | |
|---|---|---|---|---|---|---|---|
| material | cooling arc (deg) | power (kW) per jaw | Tmax ( C) | defl (um) | power (kW) | Tmax ( C) | defl (um) |
| BeCu (94:6) | 360 | 0.85 | 24 | 20 | 4.3 | 41 | 95 |
| Cu | 360 | 10.4 | 61 | 221 | 52 | 195 | 829 |
| Cu - 5mm | 360 | 4.5 | 42 | 117 | 22.4 | 129 | 586 |
| Cu/Be (5mm/20mm) | 360 | 5.3 | 53 | 161 | | | |
| Super Invar | 360 | 10.8 | 866 | 152 | | | |
| Inconel 718 | 360 | 10.8 | 790 | 1039 | | | |
| Al | 360 | 3.7 | 33 | 143 | | | |
| 2219 Al | 360 | 4.6 | 34 | 149 | 23 | 79 | 559 |
| C R4550 | 360 | 0.6 | 25 | 5 | 3.0 | 41 | 20 |
| | | | | | | | |
| BeCu (94:6) | 90 | 0.85 | 25 | 8 | 4.3 | 41 | 86 |
| | | | | | | | |
| BeCu (94:6) | 45 | 0.85 | 27 | 2 | 4.3 | 46 | 101 |
| Cu | 45 | 10.4 | 89 | 79 | 52 | 228 | 739 |
| Cu - solid | 45 | 10.4 | 85 | 60 | 52 | 213 | 542 |
| 2219 Al | 45 | 4.6 | 43 | 31 | 23 | 89 | 492 |

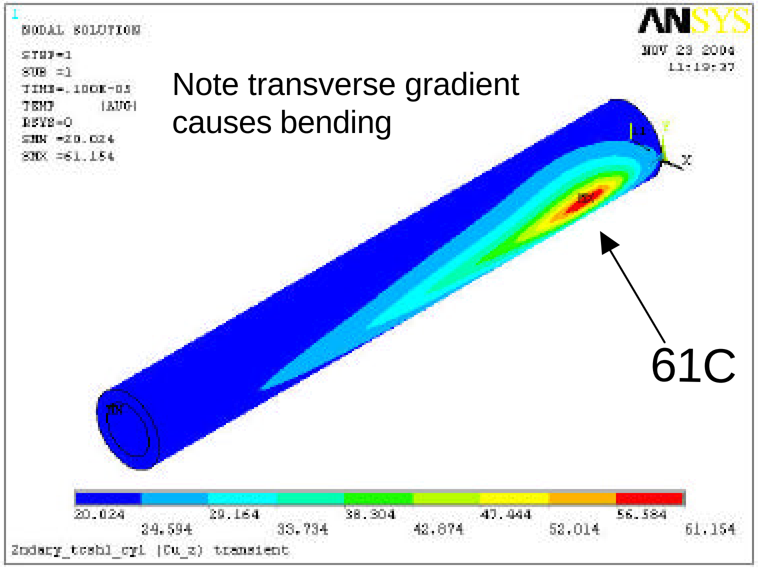
Notes:
1. BeCu is a made-up alloy with 6% Cu. We believe it could be made if warranted
2. 2219 Al is an alloy containing 6% Cu
3. Cu/Be is a bimetallic jaw consisting of a 5mm Cu outer layer and a 20mm Be inner layer
4. Cu – 5 mm is a thin walled Cu jaw
5. Super Invar loses its low CTE above 200C, so the 152um deflection is not valid
6. Green shading: meet our suggested alternative spec of 50um for SS and 200um (~1$\sigma$) transient.

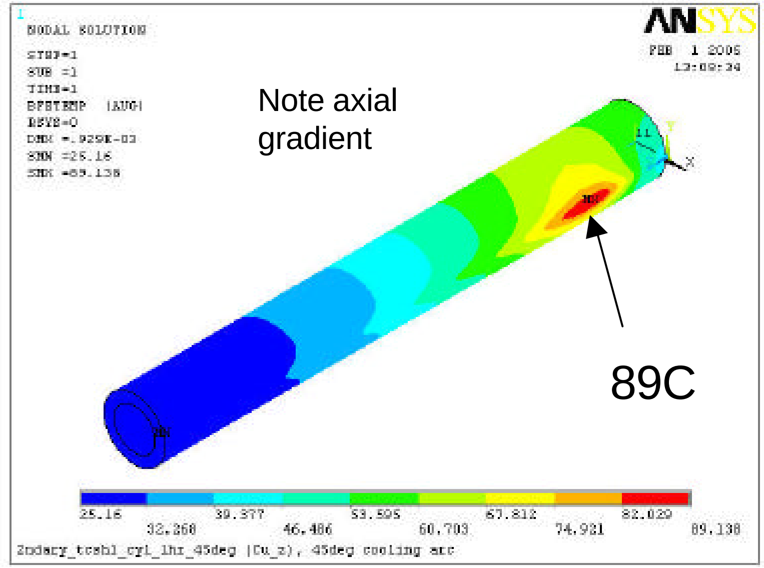
# Jaw Materials - discussion

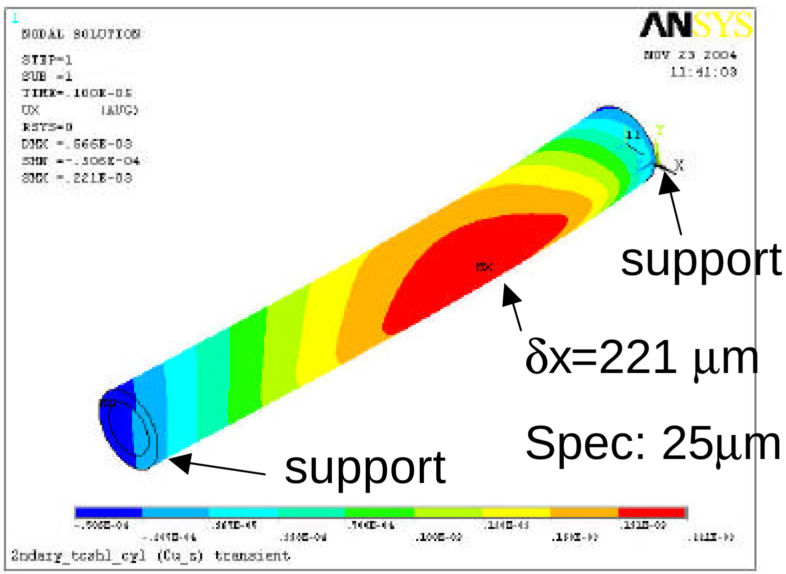
- Only graphite meets the 25um deflection spec for both operating cases. Graphite unacceptable for technical and practical reasons.
- Be-containing jaws meet the spec for the SS case but not for the transient. Also, Be is unacceptable for environmental/safety reasons.
- Al benefits from the reduced ($45^{o}$)cooling arc. It nearly meets the spec for SS, but isn't close for the transient. Nor does it meet SLAC's proposed alternative spec (50um SS, 200um transient) for the transient case.
  - Dividing the jaws lengthwise in two results in ~120um deflection of each part
  - Use center aperture stops - the jaw deflects away from the beam
- Ti showed promise in 2-D simulations, but wasn't analyzed in 3-D. It should be revisited and its thermal deflection calculated.

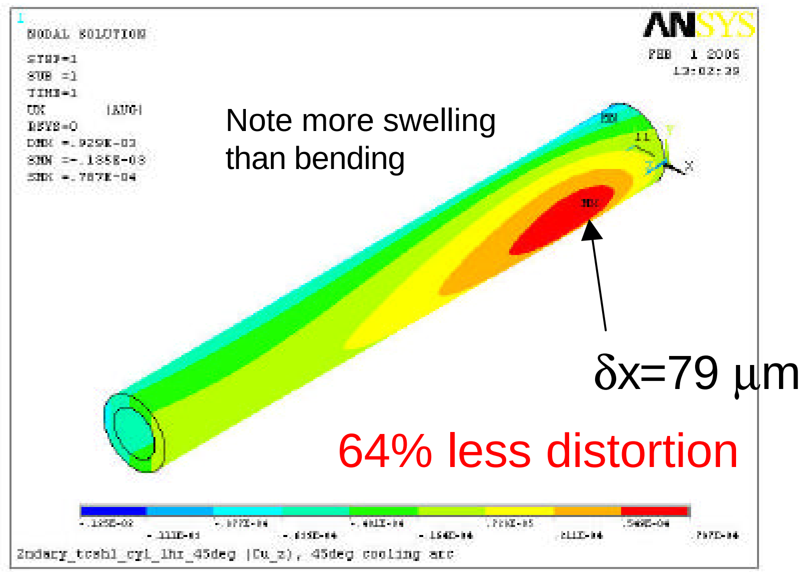
# 360º cooling of I.D.

# 45º cooling arc

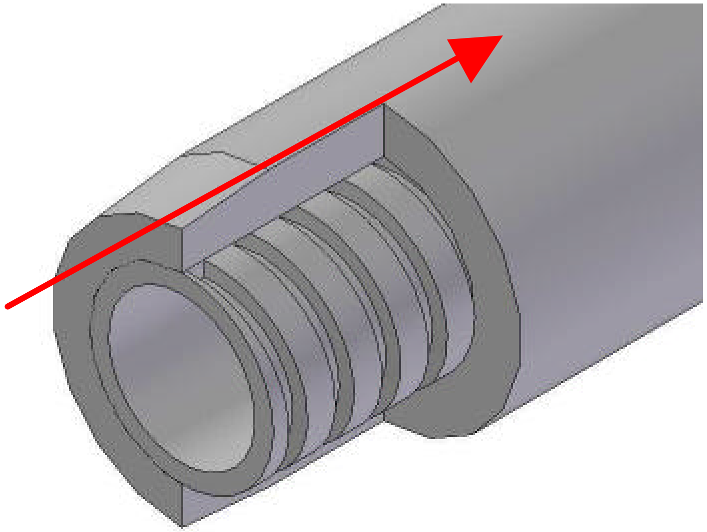


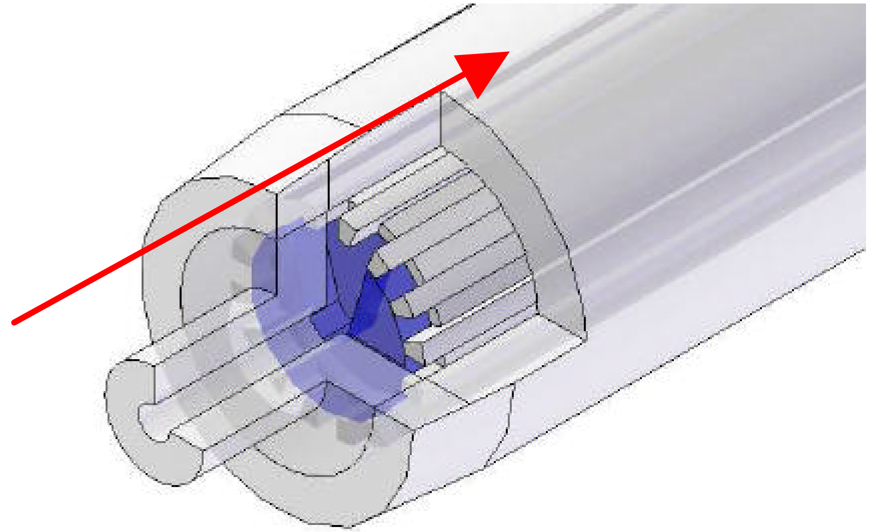



# 360º & limited arc coolant channel concepts

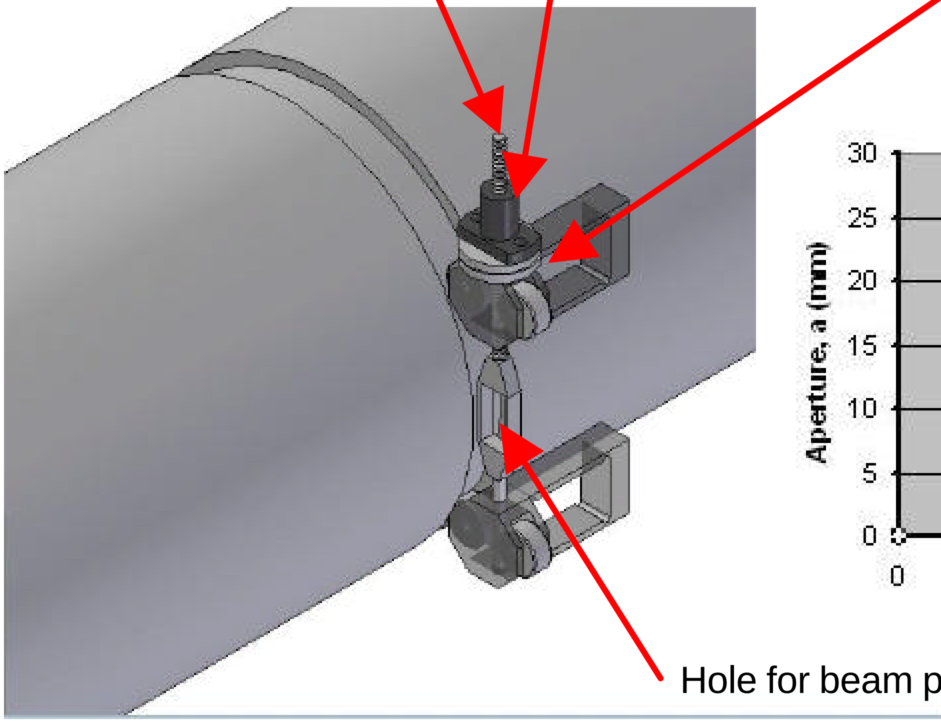


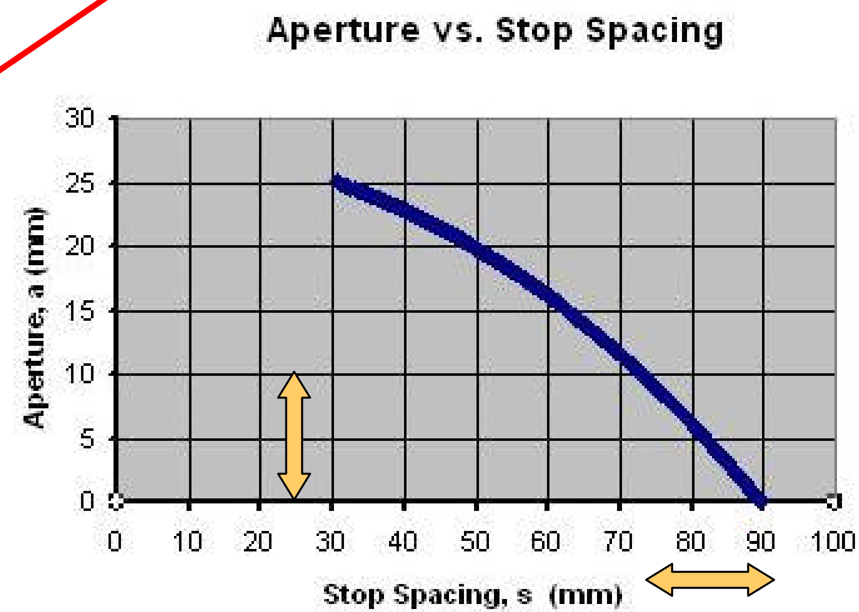


360º cooling by means of a helical channel.  Lowers peak temperatures but, by cooling back side of jaw, increases net ΔT through the jaw, and therefore thermal distortion.  Could use axial channels.

Limited cooling arc: free wheeling distributor – orientation controlled by gravity – directs flow to beam-side axial channels regardless of jaw angular orientation.   Far side not cooled, reducing ΔT and thermal distortion.

# Stop Roller Details



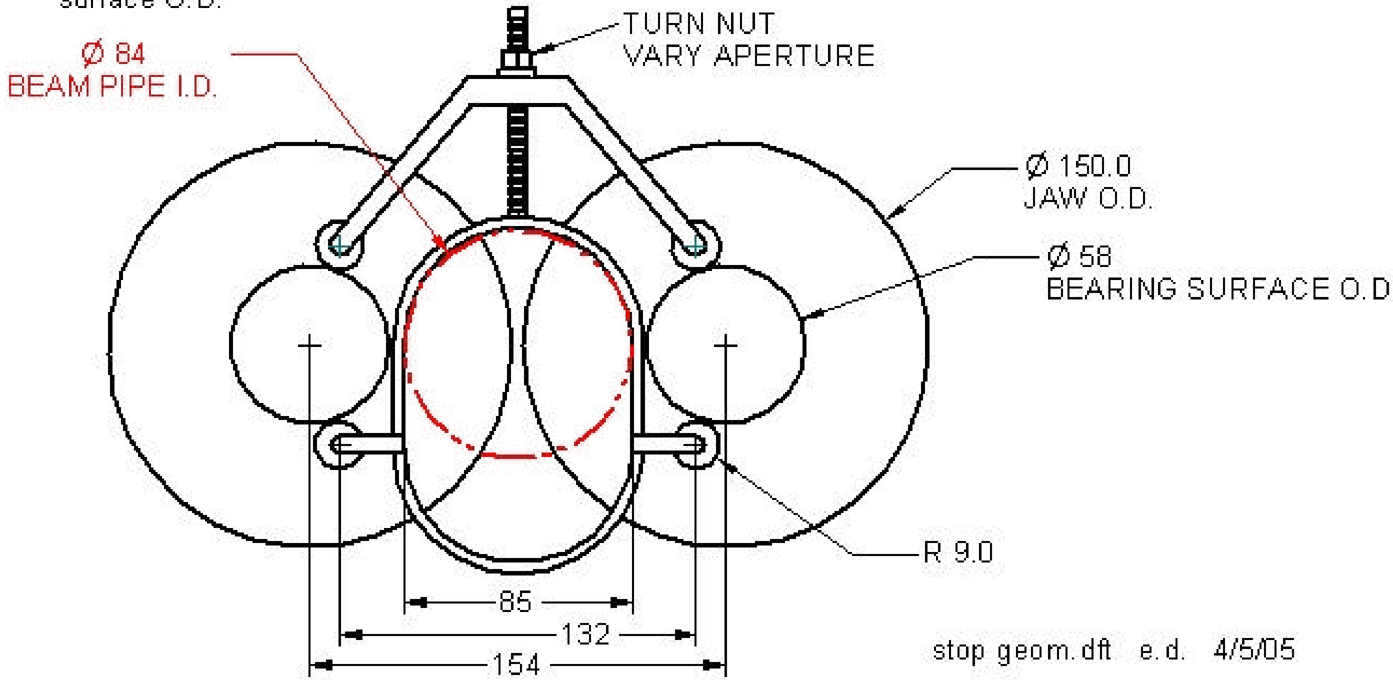

As shown in current model: aperture range limited to ~ 10mm. This can be improved but this mechanism will not be able to produce the full 60mm aperture. Auxiliary jaw retracting mechanism needed. Also note possible vulnerability of mechanism to beam-induced heating.

# Alternate Stop-Roller Design

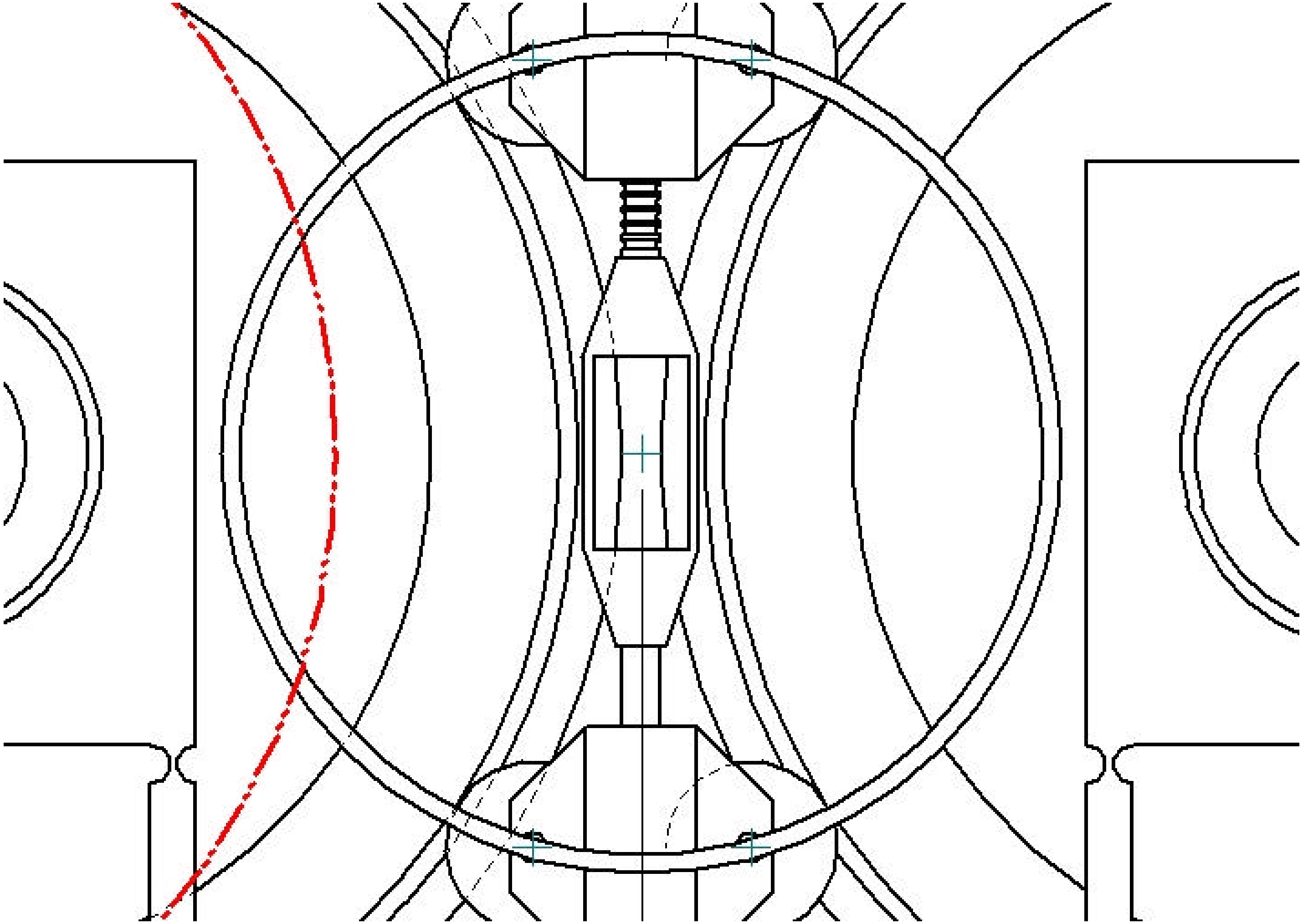
Schematic aperture stop geometry for location in center of jaw for case where no components are allowed to intrude into beam pipe.

Problems:

1. axial flow of cooling water blocked by deep groove in jaw
2. range of jaw motion limited by small diameter of bearing surface
3. accuracy of jaw positioning very poor at minimum aperture, where max accuracy is needed. Also: high actuation force in this regime.
4. greater sensitivity to thermal expansion due to increased stop roller spacing
5. Increased spacing (132mm) of stop rollers requires more robust support (flex-hinged parallelogram - not shown).
6. Reduction of jaw O.D. would have increasingly adverse effect on bearing surface O.D.

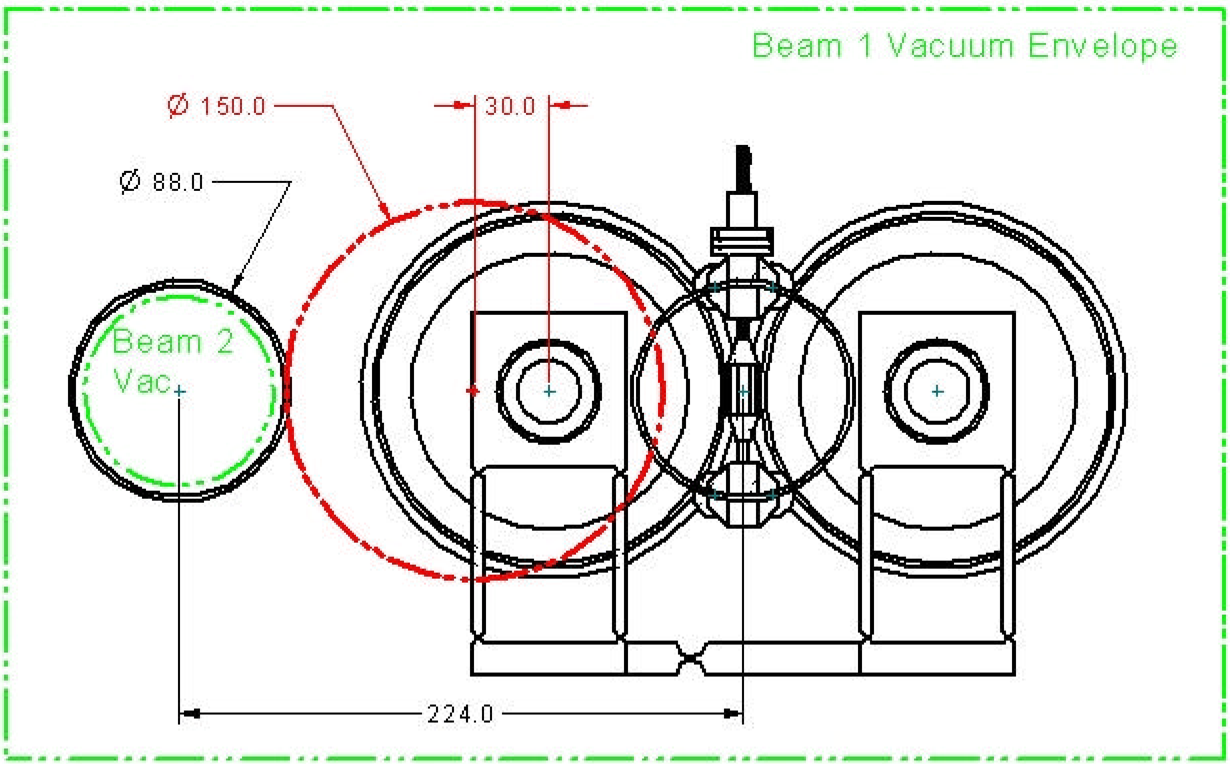


# Beam's Eye View of Aperture Mechanism



# Geometrical limits due to 150mm rotor, 224 mm Beam Axis Spacing

30mm jaw travel (in red) causes jaw to intersect adjacent beam pipe. No space for vacuum chamber wall. Resolution: 1) smaller jaw diameter 2) vacuum envelope encloses adjacent beam pipe 3) less jaw motion 4) reduce diameter of adjacent beam pipe.



# Issues with present LHC Collimator Concept

- Deflection spec will be very hard to meet
  - Relax deflection spec
  - Permit use of Be
  - Reduce jaw length
- Aperture stop mechanisms vulnerable to beam heating/damage
  - Relocate ball screw outside beam path – like NLC (jaw ends only)
  - Stop rollers unavoidably within region of beam pipe
- Space limitations prevent the use of 150mm diameter jaw while maintaining the 60mm max aperture.  Some combination of the following required to fix the problem
  - Reduce jaw diameter
    - Will likely increase deflection
    - Adversely affects aperture stop mechanism
    - May require re-tooling of FLUKA and ANSYS simulations
  - Reduce opposing beam pipe diameter
  - Include a pass-through for the opposing beam in the collimator vacuum chamber
  - Reduce the maximum required aperture

# Issues with present LHC Collimator Concept - continued

- Jaws must fully retract in power-off condition
  - Spring load jaws outward. Inward-forcing springs (necessary in any case) sized to overcome outward-forcing springs and grounded on solenoid or air pressure-loaded device which gives way when power is off. (how to reset?)